2nd Response to the Illinois Commerce Commission Notice of Inquiry (NOI) Regarding Electric Vehicles

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Using Electrified Vehicles Technology for "Valley Filling" of Grid Load

Long-term motivation.

Overview. The first sentence of the NOI asserts that as "environmental and climate issues become more pressing" the viability of electric vehicles as an alternative to internal combustion engine vehicles is increasing. In this discussion I interpret the word "environmental" to mean "urban air quality" and "climate" to refer to greenhouse gases, primarily carbon. Potential to reduce carbon emissions is specifically mentioned in the last sentence of the first paragraph of the NOI. Long-term strategy to implement electric drive has in the past been focused on improvement of urban air quality, with a focus on developing "zero emissions vehicle" technology. Urban vehicles are considerably different from vehicles chosen by residents of small cities and rural areas. Focusing attention on vehicles used in the most dense and populous urban areas promotes vehicle technology options that may not be functional in a mass market serving the diverse transportation needs of all citizens.

In these comments I discuss the needs to adapt technology incentives toward the needs of the mass market, in order to bend the trend in technology toward across the board functionality for all types of transportation. Affordability is as important as functionality, so the discussion focuses on controlling costs of electricity to better enable functional plug-in electric vehicles to realize cost savings.

Fuel supply for vehicles has historically been provided by refined petroleum products. Focusing technology development effort on vehicles using refined petroleum products also leads to technology development that is, in effect, designed to benefit a relatively few states that produce the majority of U.S. domestic oil supply. Development of alternative local fuel resources to provide import substitution for those states with little oil, but abundant renewables, is a strategy that can increase economic growth in such states, including Illinois.

Further, competition is fundamental to price stability, which also provides economic benefit. Advocates of plug-in electric vehicles often tout both the low price *and relative stability* of average annual national electricity prices, leaving out the fact that electricity prices vary significantly by location, season and time of day. In a highly respected treatise on utility rate making, Bonbright (pp. 396, 397) emphasized the importance of stable rates based on estimates of long run costs, rather than rates based on short run marginal cost.

> In short, the price elasticity of demand for utility services can be expected to be much greater in the fairly long run than in any very short period of time. But if utility rates were to be made as volatile as would be required by the mandate of conformity to short-run marginal costs, they would deprive consumers of those expectations of

"reasonable continuity" of rates and rate relationships on which they must rely in order to make rational advance preparation for the use of service.

He also provided astute and informed discussion of the problem that long run marginal cost for utilities will generally be below average cost, so *strict* adherence to long-run marginal cost pricing is not desirable. Since utilities must generate enough revenue to cover total long-run costs, utility regulators should define long run marginal cost "only in general terms and should be left for whatever nicer definition may be required in the light of the particular rate-making problem." Options for rates that I discuss in my submissions should be regarded in this light.

In effect, the comments I made in October and these November comments are intended to help Illinois think about ways to steadily and cost effectively shift the long-run fuels mix of transportation vehicles to domestic low carbon fuels rather than fuels requiring importation and use of carbon in the form of crude oil.

Functional efficiency. Bonbright (p. 122) defines functional efficiency as "whatever rate differentials are best designed to stimulate the optimum use of plant capacity as well as best designed to avoid the necessity of an uneconomical expansion of that capacity." In a hypothetical perfectly regulated world, Bonbright (358) contends that "a skillfully designed system of rate differentials would so distribute the burden of paying for capacity costs among consumers of services rendered at different periods of time, that the company's load valleys would be raised and its peaks would be lowered to the level of a plain. These differentials would be based on relative demands …rather than on cost analysis". The suggestions I make are intended to relate to the probabilities of increasing off-peak demand for renewable electricity while at the same time avoiding on-peak demand increases. Costs (rate change ideas) from my October submission were rough guesses of what utilities might find reasonable, considering examples of what a few other utilities have done.

Hopefully, refinements of valley filling rate structures would promote new uses of service. Off peak rate reduction would be limited because a utility "*must* charge more than incremental or marginal costs for some of its services in order to cover total costs. And off-peak service is likely to be among those services that can best stand a charge of this nature." (Bonbright, p. 359). In other words, even if off peak operations costs are very low, utilities may often charge more than those operations cost so that even off-peak users would contribute some of the utility revenue devoted to capital costs.

Effectively using grid capability via available vehicle technology.

Using grid capability

Avoiding adding to the peak. "Utility rates, in so far as they are cost determined, must include charges for the *probability* that the service to which they supply will be taken at the time of the system peak" (Bonbright, p. 360). In my October submission, I effectively asserted that the higher the residential kW charging rate chosen by a plug-in vehicle consumer (3-20 kW), the greater the probability of adding load at peak periods. Similarly, if a PEV owner plans to use 30-300 kW direct current fast charging (DCFC) to support long distance intercity travel, the probability of charging in the afternoon at the regional system's summer peak will be much greater than if the plug-in vehicle does not have such capability. Suppose the consumer deems high kW in either or both cases to be necessary. One may infer that the ability sought and therefore the likelihood for charging at the daily or annual peak is much greater. The total effect of cumulative kW of capability of such vehicles has a far greater potential to cause increases to peak load than for plug in vehicles charged with Level 1 equipment (1-2 kW) at the residence and having no DCFC capability whatsoever. For utilities and the grid, the least cost long run solution should be plug-in vehicles using existing gas station refueling locations for daytime refueling to support long distance travel, while reliably charging off-peak (i.e. valley filling without peak growth) at no more than a 2 kW rate within the utility service area.

Managing off-peak "valley filling" charging. Another factor discussed was the value of control of vehicle charging to regional system managers. Value to the grid in either the form of (1) demand response or (2) vehicle-to-grid electricity supply requires timely and consistent connection to the grid. Inconsistently, marketing high kW charging as a feature that allows the plug-in electric vehicle owner to charge rapidly and disconnect promotes travel to (and parking at) points removed from the grid.

Fleets whose vehicles travel many hours per day will have the problem of long-duration daytime disconnection. This will primarily be a long-term problem that implies difficulty of using fleets to absorb variation of solar energy. School "E-buses" during summer months are one alternative that is an exception; the problem would still apply to municipal E-buses. Also, automated fleets — that *may* serve the role of taxis for low income persons and persons whose driving options are limited — will be disconnected during daytime operations. Those looking for a technological solution are working on roadway charging, particularly in Europe. However, according to what I have read, the winds in Europe are far more likely than in the midcontinent to be strongest in daytime. If so, developing technology to absorb fluctuating daytime renewables is considerably more important in Europe.

In the midcontinent, implementation of overnight fleet charging control seems a considerably more promising — and considerably less costly — way to manage fluctuating wind supplies than in regions where both wind and solar power peak during the day. Even so, just enabling nighttime control is an incomplete regional-renewables capture strategy. The fleets just discussed have problems of long duration absence (either every day, or most months) from cost-effective daytime connection enabling collection of solar on sunny days. Alternatively, giving private vehicles a long duration parking and charging spot at both the place of employment and the residence is the most promising way to allow for efficient capture of fluctuating day-to-day peaks of wind *and solar* energy.

For vehicles used for work commuting, I emphasize the need for long-duration, low power charging at a single workplace location. Should the workplace instead choose to install level 2 chargers — each with several kW of charging capability — and shuffle vehicles in and out of charging and other parking spots, then fewer vehicles will be connected to the grid at any single point in time. Should such Level 2 charging locations be used for grid services, lunchtime disconnections would likely be common, creating a "trough" in supply of connected daytime capacity.

Available vehicle technology.

Short range plug-in hybrids. A significant number of today's imported European plug-in hybrids have all-electric range less than 20 miles. Providing both residential and workplace charging for these vehicles can enable them to electrify more miles per day. In the case of European manufacturers, most do not provide a hybrid powertrain option without a plug. When operating as a hybrid many of the plug-in hybrid vehicles are more efficient than any of the gasoline only versions sold in Illinois by these manufacturers. Accordingly, if lower monthly electricity charges are provided to those customers of European plug-in hybrid models that can be and are charged at Level 1, then Illinois will indirectly obtain some gasoline consumption reduction when the vehicles operate as hybrids (in addition to the savings obtained when they operate electrically).

Long range plug-in hybrids. Long range plug-in hybrids using Level 1 charging at the residence and at work could provide a great deal of day-to-day demand response capability without need for sophisticated minute-by-minute or hour-by-hour control.

<u>Cars.</u> The engineering calculations are simple and pragmatic. If as our starting premise the portion of the vehicle fleet "designed" to flexibly capture fluctuating wind and solar has assigned long duration parking and charging at the same two spots each day, and if the vehicle is at one of those two spots an average of 20 hours per day, then the most simple calculation says that minimum capability standard plugs and circuits could provide 20 kWh. The three leading selling PHEVs require 25 kWh or 31 kWh per 100 miles. In the first case, 80 miles of driving could theoretically be provided, but the limiting factor would be 25 miles per full charge, so 50 miles could theoretically be provided. In the latter two cases 64.5 miles of range could be provided and full charge limitations would not be binding.

The average U.S. light duty vehicle is driven between 11 and 12,000 miles per year (https://www.afdc.energy.gov/data/10309) Assuming vehicles used for work are driven on 90% of the days of the year (329 - not always for work though), each average day of driving at 13.000 miles per year (vehicles driven to work have higher daily miles than other vehicles) would be about 40 miles per day. If use for work occurred 246 days per year (allowing for 5 days per week with holidays, vacations and sick days) and average daily travel on work days was the same as for other days, 9720 miles of travel could be electrified on those days. If for half the remaining non-work days when the vehicle was used, it was parked overnight at the residence before departure (42 days), and if charged for 12 hours, then each of the two inefficient plug-in hybrids could be driven 39 miles per day all-electrically, for a total of 1640 more miles of electrification. Under these rough assumptions, about 87% of miles could be electrified, even without public charging.

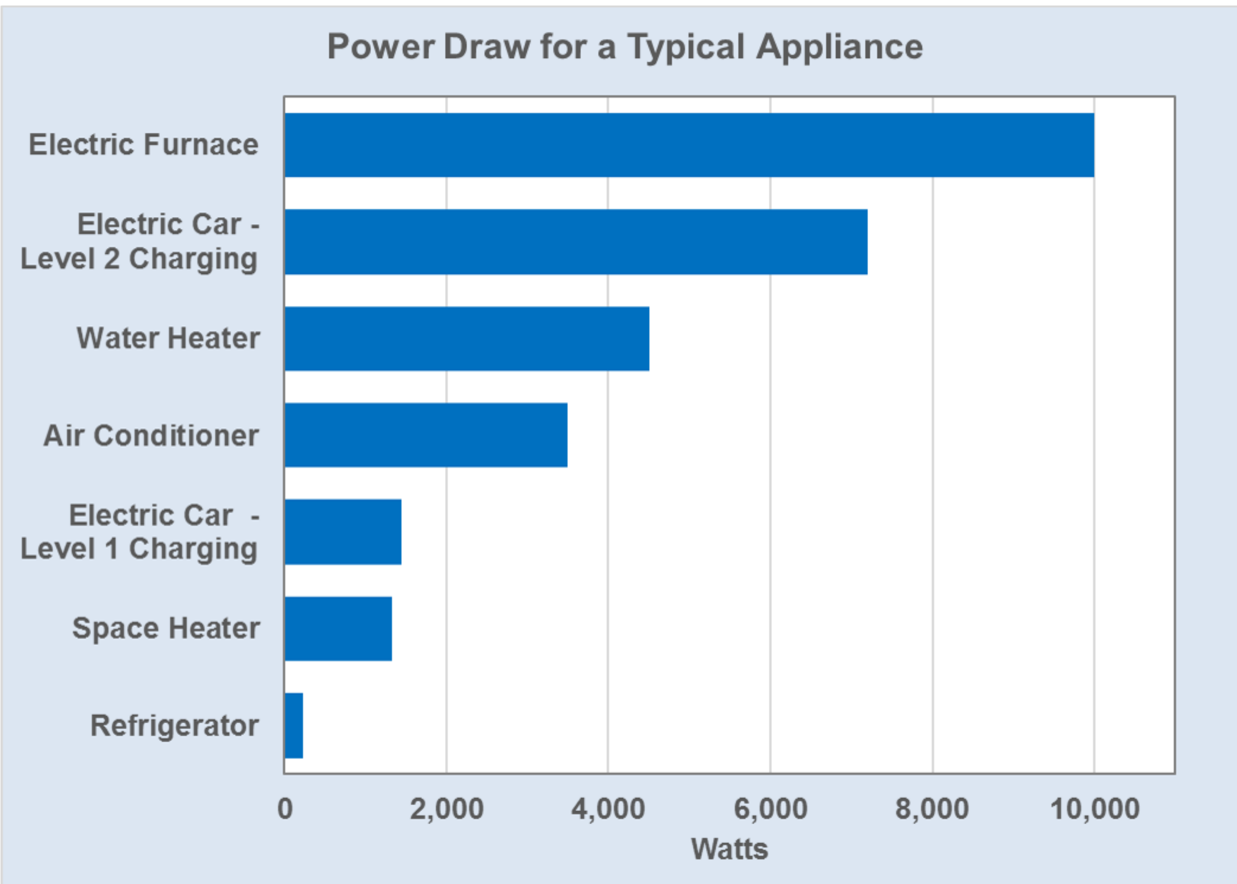
If (as I recommend), new workplace charging spots were Level 1 operating at 2 kW, this would increase the "headroom" for charging either at work or the residence and meeting the full daily driving needs for the workday electrically. The most limited of the three plug-in hybrids would still be able to achieve 50 miles per day electrically, about 10 miles more than the estimated usual day requirements. Thus, plug-in hybrid cars with all-electric range of 25 miles or more could electrify most miles of travel and do so while having the potential to shift some charging between day and night and still fill the day's needs. The latter two plug-in hybrids each have a range considerably more than 40 miles, so they would have the ability to shift all or nearly all their charging between day and night depending on whether solar or wind energy was anticipated to be most available on a given day.

<u>Other light duty plug-in hybrids</u>. Most plug-in vehicles sold to date have been passenger cars. However, recent leading selling introductions include a minivan from Chrysler, and sports utility vehicles (SUVs) from Mitsubishi and BMW. An electric fill-up requires from 8 to 13 kWh and range varies from 14 to 32 miles. These are considerably less electrically efficient than passenger cars, requiring from 41 to 59 kWh per mile. 20 kWh of charging per day at 1 kW would provide 34-49 miles per day. However, if 7 of the hours were at work with 2 kWh, then even the most inefficient of the three could theoretically realize 46 miles per day, meeting the needs of nearly all commuters. In the case of the least electrically efficient

vehicle in these three examples, the 8 kWh battery pack capacity would be limiting, so two refills would only result in 28 electrified miles per day. These rough computations indicate that if *even larger* SUVs and pickup trucks are electrified, standard plugs may not allow full electrification of a day's miles for many owners.

Battery-electric vehicles. Within this category, I group both the all-electric vehicle and the range extended electric vehicle.

All-electric vehicles. The four leading selling all-electric passenger cars have ranges from 150 to 335 miles. The website fueleconomy.gov reports times to complete a full charge is from 8-12 hours (https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=39836&id=39839&id=40812&id=40520). with a standard charger. The design feature illustrated is an ability to fully charge in one night. It is inferred that an owner can drive for multiple days without recharging again at home. A Department of Energy 2017 illustration of power demands for typical electric vehicles vs. appliances is shown below. This figure implies that a home with natural gas heating, a natural gas water heater, and an air conditioner would not have enough power to charge an all-electric vehicle at the Level 2 power level.



https://www.energy.gov/eere/vehicles/articles/fact-995-september-18-2017-electric-vehicle-charging-home-typically-draws

For households without a high kW electrical system and a desire/need to use Level 1 charging, the question would be whether existing or slightly upgraded circuits in the garage or carport would work.

The electric car sales leader Tesla recommends that owners install their charging equipment (https://www.tesla.com/support/home-charging-installation/mobile-connector) and leave the Level 1 charger in the car. However, it appears in this video that Tesla has created an ability to vary the amperage when an owner uses this charger (https://www.youtube.com/watch?v=CaLDA3kYpbo). Amperage can be dropped as low as 5 amps, in which case charging would take a very long time. Nevertheless, this does show that the technical option to charge at 8 amps exists in the leading selling all-electric vehicles from Tesla. I noted this capability for General Motors in my October submission. Nissan was not found to provide ability to drop amperage to 8 amps. Nissan includes a long list of cases where a circuit would not be suitable for charging, including a residence more than 40 years old, or one using fuses instead of circuit breakers. Risk of fire if outlet or circuit capacity is not enough is mentioned. (https://owners.nissanusa.com/content/techpub/ManualsAndGuides/LEAF/2018/2018-LEAF-owner-manual.pdf) The next section mentions the discovery that BMW has also allowed for owners to adjust amperage for Level 1 charging in its i3 model. These additional investigations, completed after the October submission, support the argument that circuits should routinely be inspected by electricians and guidance offered to customers before purchase of plug-in electric vehicles.

These discoveries also imply that electric vehicle manufacturers recognize the impediment to mass market success represented by an inadequate number of suitable plugs and circuits to meet potential customer needs. Though it is not advertised, many appear to have recognized and prepared for the likelihood that many future customers will not be able to afford to upgrade to Level 2 but could find the vehicles functional for their needs with regular overnight charging.

Range extender electric vehicles. At the present time, the only range extended electric vehicle on the market from a major manufacturer in the United States is the BMW i3 REX. This is a compact car. A range extender pick-up truck (the W-15) is also available in small quantities from Workhorse of Ohio (https://www.trucks.com/2018/03/12/workhorse-production-w15-electric-truck/). The truck has a claimed electric range of 80 miles and total range of 310 miles, using a small BMW engine operating on gasoline. The 2018 BMW i3 REX has a rated electric range of 97 miles electrically and 83 more miles on gasoline. The short range of the i3 REX on gasoline is due to a regulatory mandate from California. The long gasoline range of the W-15 would disqualify it for any credit in California. Gasoline range is not allowed to exceed electric range if a REX is to obtain a Battery Electric Vehicle (BEV) credit in California.

Investigation of the charging options for the BMW i3 located a Swedish web post that indicates that BMW has also decided that the option to charge at low amperage should be provided to consumers (https://bmwi3owner.com/2014/02/charger/). The three settings available in Sweden in 2014 were (1) low, (2) reduced, and (3) maximum. Low was estimated by the Swedish author to provide 5.95 amps, Reduced to provide 8.7 amps, and Maximum was 11.5 amps. That i3 owner charged every night at 8.7 amps and chose to forego the expensive higher power charger available from BMW. These settings also appear to be available with Level 1 charging in the U.S. version as of 2018 (https://www.youtube.com/watch?v=resUyn7tyYU). This youtube view also confirmed that the i3 has the charge by departure option advocated in my October submission. The i3 REX has a small motorcycle engine that allows series operation on gasoline. When running on gasoline, the U.S. version is "hobbled" relative to the European version because of the California regulations.

Controlled charging of battery electric vehicles.

Individual vehicles.

As battery pack size and electric range of plug-in vehicles increase, the potential benefits of active minute-by-minute and hour-by-hour control for demand response to collect fluctuating renewable generation increases. The rules of the game — that the vehicle must be connected to the grid — still apply. In my prior October NOI response I presumed that the utility uses information-collecting strategies that allow it to learn where the least costly opportunities for higher kW Level 2 charging can be found. Based on the figure above, all-electric homes with electric heating are likely candidates. Even when utilities understand where the most cost-effective locations for controllable Level 2 supply equipment might be, they still need cooperation and support from vehicle manufacturers.

As I understand it, on the vehicle side, the effects of fluctuating rates of charge on vehicle battery life remain to be determined. Controlled, variable rate charging of plug-in electric vehicle batteries remains experimental. Familiarity with battery attributes tells me that the least damaging operations strategy will have the battery pack charge consistently fluctuate around a 50% state of charge — half full. In this respect, the more electric range that a vehicle has, the better. Half full all-electric vehicles with long range can readily provide all the electric drive needs on a typical day of driving. The percentage variation of charge around the mid-point will be least for long-range all-electric vehicles using proper charge management, which will in turn be good for battery life. Note that the best way to keep the charge of an all-electric vehicle near the 50% point would be to charge and discharge it every day, with only the needed capacity for the day being used. On the other hand, occasional extended charging would be desirable on days when extra renewable energy was available.

In any case, it is not evident to me at this time that the vehicle manufacturing industry has been focused on development of controllable vehicle supply equipment and variable rate vehicle charging for new vehicles. This is an option for the future, not the present.

Aggregation (fleet management and control).

My impression is also that grid managers have not targeted plug-in electric vehicles as a source of grid management. Rather, because grid managers have developed contractual requests for grid management capability, researchers have tried to develop techniques and technology that might ultimately allow plug-in vehicle batteries to provide grid management services. Some of the research is directed toward creating value out of used vehicle batteries that no longer meet vehicle manufacturers requirements, but still have potentially useful capabilities. The attempt is to create long-term "value" that can assist in success of plug-in vehicles.

At this time, I see grid managers as only distantly interested in establishing control of new plug-in electric vehicles. My reading tells me that the strategy is to pass the problem off to "aggregators". An aggregator would take on the responsibility to coordinate charging behavior of many plug-in vehicles and, in effect, become a single legal entity responsible for the functioning of a system whose attributes are specified by the system operators. Fleets in many respects represent a good opportunity to implement aggregation and coordinated control of many vehicles. However, problems with daytime fleet availability to the grid imply that this may be a cost-effectiveness dead end. Based on the discussion here, the workplace would appear to be the best location for aggregation.

By an absence of discussion, the literature tells me that there are management costs involved in aggregation and control that are generally not folded into cost analyses. Shuffling multiple vehicles to make best use of a Level 2 charge spot during a workday involves loss of employee time, as employees move vehicles around during the day. I have yet to see an explicit estimate of this as a cost. Even when charging management is accomplished by fee structures designed to penalize connection while not charging, the employee must leave work activity and move the vehicle. Secondary costs related to loss of employee focus on work tasks should be included when workplace managers plan for high rates of employee fleet charging that includes workday vehicle shuffling. A minimum initial cost charging capability that could attract high tech employees (just a few controllable Level 2 charging points to "show the flag" regarding corporate commitment) could be good initially. However, pragmatically that approach must be balanced against long-term effects of added shuffling of employees between the workplace and parking spots. Encouraging and maintaining proper "charging etiquette" can become yet another mid-level management problem.

My judgment is clearly that the long-term type of vehicle use that could be most favorable for grid control would be constant connection to the grid overnight at the residence and during the day at work. Dedicated parking spots with low power charging equipment for both locations would be desirable. As I have discussed, if 2 kW level 2 charging at the workplace were the standard approach, it is likely that overall charging kWh available would exceed daily needs of most employees. For plug-in hybrids and long-range all-electric vehicles, the workplace could promise that a total kWh of supply per parking spot per day (8-10 kWh, perhaps) would be provided during the span of the workday, but that the rate of charging might be varied. Little risk of loss of daily functionality would exist for plug-in hybrids on days when the vehicle was not at the parking spot for the allotted hours. The workplace could control the charging rate of all vehicles from a central spot, in response to signals regarding renewables supply. This would be the equivalent of the aggregation that grid system managers have sought. For overnight residential charging the utility would probably need to become the aggregator, working with customers who can readily afford a Level 2 charger, and inserting control equipment when the charger is installed.

Adapting Emerging Technology to an Alternative Long-Term Strategy for the Midcontinent

The currently dominant long-term vision.

Consider these recommendations for aggressive implementation of workplace charging primarily using low power daytime charging of plug-in hybrids and range extenders to an alternative emphasis on long-range all-electric vehicles seldom charged at work, with high power daytime charging along and near interstates. For many technology-oriented advocates the long range all-electric vehicle using rapid high-power charging is the end game of the technology development effort. Since such a vehicle can be rapidly charged at home at any night the owner prefers, it will never be charged at work. The idea that the nation is focused on the latter path is consistent with the 2018 reduction of support for the U.S.

Department of Energy's "Workplace Charging Challenge" (https://www.afdc.energy.gov/fuels/electricity_charging_workplace.html).

Wind, solar and biomass to support plug-in electric vehicle success – an alternative vision.

Background. From my perspective, there are unique "midcontinent" driving patterns and wind generation patterns that suggest different plug-in technology priorities in this region. Broadly, I refer to the area between the Rocky Mountains and Allegheny Mountains. Within this region, temperature extremes are also a relevant problem in most locations. Cold temperatures reduce the range and recharge times of all-electric vehicles. Hot summer temperatures and resulting air conditioning use have driven up the midcontinent's peak vs. average electrical demand relative to coastal locations where air conditioning needs are significantly lower. This makes incremental summer generation costs higher, which in turn makes deterrence of summer peak charging more desirable.

On the other hand, the high existing peaks and grid capability also creates an opportunity because of a much deeper off-peak valley, so that more off-peak valley filling charging can be supported in the mid-continent than in areas less dependent on air-conditioning. From a regional perspective long-distance driving of all-electric vehicles recharged on summer afternoons could stress the overall grid. From the point of view of an individual house, the long-term goal of off-peak valley filling charging could be thwarted if a trend of consumer demand for plug-in vehicles using Level 2 charging at 5 kW and above develops. Since the NOI begins discussion by mentioning the potential for vehicle electrification in 2040, one may wonder whether the charging systems in today's houses (the vast majority of which will still exist) could support two plug-in vehicles with 10 kW or more of total peak charging power, even with overnight charging. For mass success, including for used vehicles in modest homes of lower middle-income taxpayers, I argued in my October comments that focus of automakers and utilities on developing a pattern of technically and financially feasible (and safe) Level 1 charging is desirable.

This strategy would require a regional restructuring of current national trends to meet specific midcontinent needs and to take advantage of local renewables alternatives. It appears from the tone of the NOI that it is recognized that current trends may be problematic from the point of view of utility regulators. It must be remembered that the present is a very early point in what one hopes is widely successful technological evolution and market diffusion of much more efficient and clean electrified vehicle technologies. Engagement now is imperative and opportune. It is likely early enough. Technologies are adequately diverse and are still under development. In my opinion, under present regulatory (i.e. California regulation) and allowable evolution of financial incentive structures (available to states, communities and utilities) technological alternatives can readily adapt to what utility regulators must require under present good practice. I emphasize that the midcontinent is different from California and should retain its flexibility to go its own way. Based on history, I think that the diversity of approaches is good for both locations and will ultimately lead to a better mix of technologies than if one national regulatory strategy were adopted at this time (or ever).

Potential spin-offs and technology adaptation consistent with current regulation. From my perspective, the historical California passion for technology-forcing regulation to promote all-electric vehicles to improve air quality creates an impediment for introduction of available, and less costly plug-in hybrid and range extended electric vehicles for the purpose of reducing the midcontinent's vehicle fleet carbon emissions. The perfect (the all-electric vehicle) is the enemy of the good (other types of vehicle electrification). In the process of diffusion of technology, the preferences of early advocates are often inconsistent with necessary adaptations for mass-market success.

California has a record of passing technology-forcing regulation and only backing off when the facts demonstrate that costs of the goals are too expensive. In the history of California zero emissions vehicle (ZEV) regulation, this has happened twice. The first ZEV regulation was promulgated just a few years after a hot 1988 summer with an urban air quality reversal and a 1990-91 Middle Eastern war. At the turn of the century, once vehicle electrification using battery technology of the 1990s was demonstrated — in conjunction with very low gasoline prices — to be too costly, California and the U.S. government turned to research on hydrogen fuel cell vehicles instead.

After costs of lithium ion batteries dropped and a war in the Middle East pushed gasoline prices sharply upward again, advocacy for another round of California regulation to encourage promotion of plug-in hybrids and all-electric vehicles developed (and a regulation followed). The federal government added a subsidy biased more toward plug-in hybrids than long range all-electric vehicles. This time the California regulation — thanks to technical properties and affordability of lithium ion batteries — can be interpreted as successful. It led to the great market success for long-range, fast refueling, high-power luxury performance all-electrics produced by Tesla. The new California regulation and other federal and state support led to a mix of plug-in vehicle technologies that has proven to be nationally and/or internationally marketable. Regulatory and financial incentives promoting plug-in vehicles followed soon after in other nations.

Despite the success of the fast-refueling long-range all-electric vehicle in the luxury/performance market, the most recent adaptation of this California regulation shows a degree of concession to costs of using batteries to provide long vehicle range. One might call it “hedging”. In particular, the degree of reward for long range battery electric vehicles capable of “fast refueling” has dropped, and the option for manufacturers to use what was originally a limited niche option — the “BEVx” — has been expanded considerably. The bottom line for this discussion is that the updated existing California ZEV regulations are now much more flexible regarding use of gasoline (or other fuel such as hydrogen or biofuel) to meet long range driving needs. The “x” in BEVx stands for range extension.

Only one manufacturer to date has produced and sold a vehicle qualifying for “BEVx” credits. As previously discussed, the BMW i3 had one all-electric version and one version – the “REX” (range-extender) — with a small engine and fuel tank added. The same size battery pack was used in both models. Although the REX cost more, was slightly less efficient, had limited performance when running on gasoline, and accelerated on electricity more slowly than the all-electric i3, over the three years where we internally tracked the Illinois records at Argonne, the sales share of the REX vs. the all-electric rose in every year. Within the compact size class of passenger car, the i3 (both models combined) has been the most successful of any electrified model in terms of market share. This niche success is masked in part by the declining share of compact cars in the market. Though this is what is called “suggestive evidence” and may not impress some, it is all there is to go on regarding this technological option at this time.

Although I have not had any interaction (other than reading reports and regulations) with California’s cost analysis experts, the work that I have done with colleagues at Argonne has resulted in findings consistent with the new path chosen by California regulators. To reiterate, that path expands the possibilities for manufacturers to earn electric operations capability credits under overall low emissions standards by producing vehicles that can also run as hybrids on gasoline. While the expanded "BEVx" category can only account for half of the BEV credits earned under California regulations, the rest of the country places no limits on the use of plug-in hybrids or BEVx vehicles to enable electrified miles.

Working with expert cost engineers, I have co-authored some relevant evaluations that the ICC should consider when evaluating the judgments I have submitted. For example, an assessment of the market potential of hybrid electric vehicles using nickel metal hydride batteries (Santini 19?? [AVID report]) projected in 2005 that if high hybrid cost increments and relatively low gas prices of today were to exist, the market penetration of hybrid electric vehicles would flatten out at less than 5% of the market, as it has. More recently, in 2009, in a paper featuring work of cost expert Paul Nelson (Nelson, Santini and Barnes, 2009), we predicted what were then regarded as improbably low lithium-ion battery costs in the event of large-scale production. However, these costs have since been recognized as imminently achievable.

The last paper that I co-authored before retirement addresses the implications of those low prices (Santini et al, 2018). Unfortunately, we do not conclude that long-range all-electric vehicles can be cost competitive in the mass market, even if they enable grid control capabilities that provides them with free electricity. Only intermediate range electric vehicles, plug-in hybrids and a range-extended battery electric vehicle are estimated to be cost competitive, and then only against high cost, high octane gasoline or bio-gasoline. Long range electric vehicles are estimated to be too costly for the mass market.

This finding only reflects the patterns of list prices of plug-in electric vehicles that manufacturers are posting today. Tesla delayed introduction of its touted intermediate range low cost all-electric fast chargeable "Model 3" due to concerns over corporate profitability. Even when it is introduced, the point of our paper is that the vehicle competes in the luxury-performance segment of the market, not in the mass market.

We did not include the short range all electric vehicle in our most recent paper because its functionality was regarded to be inadequate for the mass market. In other words, despite a cost competitive with gasoline vehicles, the range limitations create a functional impediment to mass market success. In the marketplace of 2018, where manufacturers have introduced multiple plug-in powertrain options in the same vehicle configuration, at price points lower than for currently marketed long-range electric vehicles, the plug-in hybrid powertrain is less expensive than the relatively short-range all-electric vehicle and sells at a much higher rate.

The implications of our recent paper (Santini et al, 2018) and the present marketplace is that long-run mass market success of "electric" vehicles will come only if those vehicles keep their battery pack size (and costs) limited and use gasoline for long range functionality. It is the "dull" (Bonbright, p. 9) finding of a cost analyst rather than a passionate believer in exclusively all-electric vehicles.

For the regional grid manager, this may come as a relief, since the implication is that summer peak daytime fast charging of plug-in electric vehicles will not be effective in causing mass market success of plug-in vehicles. This is particularly true for the local utility (and, to some extent, a state), since provision of fast charging on interstates passing through the service area will likely primarily serve customers of other utilities, where those vehicles will charge overnight.

The “back of the envelope” estimates here imply that the near-term focus for Illinois should be on promotion of low cost, low power residential and workplace charging to support plug in hybrids and potential future range-extended electric vehicles. Such vehicles will not need installation of intercity fast charging equipment. With astute passive and targeted active management of off-peak charging at the residence and at work, long-range plug-in hybrids and range extended electric vehicles could accomplish “valley filling” without contributing to a higher grid peak.

Incentives to bend the trend. The state of Illinois can help establish the path to mass market competitiveness by supporting continuation of existing regulation and incentivizing some adaptations. First, note that the present significant success of high-performance long-range all-electric vehicles is in part because they compete primarily against vehicles with engines that require high octane fuels. Accordingly, fuel savings per mile relative to the competition are even higher than for the short-range electric vehicles competing in the mass market against economy vehicles using regular gasoline.

The existing mix of federal and California regulation is causing an increase in use of engines designed to operate on high octane premium gasoline. Because engines using high octane fuel can be designed to run more efficiently, this helps manufacturers meet the tight fuel economy standards. Unfortunately, at the time I looked, there was not evidence that manufacturers were providing flexible fuel capability to allow customers to choose between high octane E85 and premium gasoline. In any case, the trend is desirable for Illinois in the long run, since gasoline powertrains are moving toward higher cost premium gasoline. Whether by using ethanol or another high-octane biofuel blend in more future engines, Illinois farmers could potentially obtain benefit from a trend toward use of costlier high octane fuels.

The potential benefit of promotion of this gasoline cost and quality trend for competing vehicle electrification is that electricity will slowly get to compete with more expensive mass-market gasoline than at present. Another, more subtle potential benefit could be realized by promoting use of flex-fuel engines in range extended electric vehicles and in engines for plug-in hybrids. The higher the cost of fuels used in these electrified vehicles, the more effort owners will put into charging electrically. Since long-range plug-in hybrids and range extended electric vehicles can be expected to use the hybrid mode of operation for relatively few miles in any case, the added cost for high octane fuels would not be a significant burden. The added functional capabilities could be very valuable, enabling significant sales benefits. In the meantime, automakers could focus attention on efficient high-octane fuels for those engines that might be used in either plug-in electric vehicles or future conventional powertrains.

My suggestion to Illinois is that it work with other midcontinent states to develop an incentive program to support the flexible use of high-octane premium gasoline or biofuels within future long-range plug-in hybrids and range extended electric vehicles. As the rough calculations indicate, a minimum range requirement of about 25 or 30 miles could lead to plug-in hybrids capable of flexible low power charging supporting all-electric operations in everyday use. With even longer range, range extended vehicles could have even more charging control feasibility, allowing day to day variation in charging to support collection of either wind or solar on days and at times that they are most abundant. An ability to operate on either premium gasoline or high-octane bio-gasoline would assure that the vehicles could fit into rural areas both for tourists coming from major cities and for local use by residents. The spatial functionality of these vehicles would be greater than for all-electric vehicles.

I would suggest that the midcontinent support full functionality of such vehicles. Rather than limit the operations capability in hybrid mode, a minimum total range of 300 miles or more might be required for subsidy. Long distance travel on gasoline should be able to take complete advantage of available power in the battery pack, allowing hybrid mode operation at a high state of charge should the owner choose that control strategy. Leave automakers flexibility to decide how to meet customer needs. Potential inexpensive operation on electricity will make automakers want to get that right, while the benefits of full functionality in hybrid mode would make them want to get that right as well. After that, let the customer decide how to operate the vehicle to best meet their needs.

The BMW i3 list price for the 2018 i3 REX is $3850 more than for the all-electric i3. My guess is that a subsidy of $1000-$1500 should be enough to encourage any manufacturers producing future “BEVx” vehicles for California to develop a version of the vehicle that has longer gasoline range than California allows and provides fuel flexibility to run on premium gasoline or E85. A coalition of states providing such subsidies to any long-range plug-in hybrid or range extender, starting in three or four years and limited in the aggregate to a total in the low hundreds of thousands of vehicles sold (each state might set a limit, the sum of which could be higher than the grand total committed to), could “bend the trend” of plug-in technology development in a manner very favorable to midcontinent states.

This response to the NOI, along with my October NOI response, provides my professional judgments about how Illinois and the midcontinent can use plug in vehicles to cost-effectively use the grid and managed charging to capture locally available (intra-state) renewables, including wind, solar and biomass, over coming decades.

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